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WHAT GOES UP

THE GLOBAL ASSAULT ON OUR ATMOSPHERE

CHAPTER

8

The Cornfield Meet

Snowmass Village, Colorado, May 9, 1988

Sherry Rowland stood in the noonday sun slowly munching a bag of potato chips, his attention completely focused on Jim Anderson's words as they both leaned against the side of an ancient red pickup truck and talked about the momentous events of the past few months and the opening session of the Polar Ozone Workshop.

All around them other voices and forms and faces of the lunchtime crowd milled and congregated seemingly at random, forming small groups, then breaking away like collections of atoms broken from fragile molecules by the solar light and sent spinning toward new encounters. Some sat and ate their box lunches on the green grass of a cul-de-sac at the end of the driveway; others, mindful of the lobsteresque results of

mixing fair skin and high-altitude sunlight for even thirty minutes, perched on brick walls and benches under the overhang of the Snowmass Convention Center, silently drinking in the beauty of the scene from the safety of the shade. There would be little time for beauty or recreation and reflection during the coming week, since most of their days would be spent in the nearby auditorium, discussing the fate of the latest addition to the Earth's endangered list: the ozone layer.

Jim Anderson shifted his position against the pickup as he finished a sentence, watching Sherry Rowland for a response and noticing the sunlight glinting with malevolent intensity off the reddening bald spot on Rowland's unprotected head. Both men had dressed casually, but now the khaki pants and blue sweater Anderson was wearing looked rumpled and a bit warm in the 60° temperatures, yet Rowland's tropical safari shirt seemed a bit out of place as well. After all, this was still Colorado. Only a month before, skiers had slalomed past this very spot, though now there wasn't a patch of ice or snow to be seen anywhere on the upper slopes. In fact most of the two hundred scientists on the attendance roster were in holiday attire, if not holiday spirits, and some were sporting newly acquired sunburns from unprotected rounds of golf at high altitude the day before. Snowmass had been picked as much for convenience and cost as the obvious ambience. May 9 through 13 was a dead week, the off-season lull between the winter ski season and the summer tourist crowd, and the perfect time for an isolated conference in a temporarily isolated place (which is scientific ambience in itself).

Isolated, that is, except for the army of workers preparing the ritzy resort for the next round of tourists. The constant whine of power saws and the hum of motorized vehicles accompanied the whisper of thin, high-altitude air blowing across the grassy ski slopes and through the collection of alpine-style condominiums, shops, and hotel—now totally commandeered by the scientists.

A few feet away from Rowland and Anderson, a reporter

waited patiently, watching carefully for an opportunity to approach the men. Only nine writers or journalists had shown up, along with two television reporters from CNN and one from the Canadian network CBC, but those who had made the trip fully realized the importance of the issues at hand, and they all understood the amazing fact that for the next five days, almost every senior scientist on Earth with any significant role in the ozone crisis was gathered in one place at the same time. It was an incredible chance to interview the movers and shakers of the issue.

The list of names was literally a who's who of the ozone wars: Sherry Rowland, Jim Anderson, Mario Molina, Joe Farman, Susan Solomon, Mark Schoeberl, Don Heath, Dan Albritton, Paul Crutzen, Richard Stolarski, Mike McElroy, Mack McFarland, Adrian Tuck, Steve Wofsy, and many more—all of them gathered under the wing of NASA and Bob Watson's direction for what had been stylized the Polar Ozone Workshop—a scientific gathering Adrian Tuck knew was going to turn into a "cornfield meet."

Tuck's efforts as a decision maker, meteorologist, and chief project scientist during the Punta Arenas expedition had been pivotal, and his role in the months afterward was even more so. His schedule through the fall and early spring was filled to overflowing with the struggle to bring the wide array of expedition scientists to the point of consensus and written papers concerning what they had found. Though Tuck's office was on the upper floor of NOAA's Aeronomy Lab in Boulder, he saw little of it December through February. The series of meetings held to define and refine the data and conclusions from Punta Arenas seemed nearly back-to-back, culminating in a pivotal three-day conference in picturesque Estes Park, Colorado, in February.

Tuck had hoped that Estes would be the final forum. There, according to his plan, he would be able to help nudge his colleagues into agreement, reconciling (at least for public consumption) everyone's differences and emerging with a unified

view of the Punta Arenas findings as a singular set of papers none of which would be diametrically opposed to any other.

Herding snakes would have been easier. The dynamicists and chemists simply could not get past their differing views of what the data really meant. Adrian Tuck needed to defuse any potential for having the upcoming major conference in Snowmass degenerate into real-time controversy over the exact method by which chlorine destroyed ozone over Antarctica each Austral spring. Yes, there was still legitimate doubt over the precise interactions of dynamic movement of the molecules in the Austral atmospheric soup and the role of such dynamics in the chemical destruction of ozone, but it was frustrating to scientists such as Jim Anderson, who had found the smoking gun of ClO. "We *know* what's occurring. We really don't need to know all the details of how it's occurring before acting. Those problems can be solved in time."

Tuck knew the scientific community would best serve the policymakers by providing a united front with their findings and conclusions—a state of theoretical unity—but such harmony wasn't going to happen. Even though the weather cooperated in Estes in cloistering the colliding scientists (freezing temperatures, wild winds, low clouds, and gloomy conditions kept everyone huddled inside the Inn of Estes Park along the frozen shores of Lake Estes), there was no way to thoroughly mollify the dynamicists. Yes, it *is* a chemical process, the dynamicists admitted, but it's set up by dynamical actions, and it's even broken up in late November and early December by dynamics, and there are some unresolved dynamic interactions involving heat flux of the Antarctic air mass and mixing of the polar air mass and the air outside the vortex that must be resolved.

"All we need right now are chemical explanations," said others, in effect.

By April, Adrian Tuck had effectively thrown up his hands. The barrel-chested, indefatigable world-class scientist from Britain who, with walrus mustache, incisive mind, and direct

and friendly manner, had served as project scientist of the Punta Arenas expedition, knew that a peaceful consensus between the opposing camps was not in the cards.[1] "It's like the old days of railroading," he said, "when two trains, unable to communicate, would speed unknowingly toward each other on the same track through the middle of Kansas. Eventually, there was going to be a cornfield meet between the two—guaranteed to be messy."

And in this case, Tuck knew, in the high-altitude ski resort a few miles down the road from chic, eclectic Aspen, Colorado, there was, in fact, just such a cornfield setting: Snowmass.

Long before the inevitability of scientific conflict in Snowmass became apparent to Adrian Tuck, the apparent futility of providing adequate evidence to the chemical industry—and the policymakers who could force their hands—had become a frustrating, revolting reality to everyone involved with the expedition.

"What is it going to take to convince them?" The question had become almost a battle cry as soon as the team had returned from Punta Arenas and the reality had dawned that even their galvanizing preliminary findings weren't yet enough to retard CFC production worldwide. Nearly two hundred scientists in Chile and Antarctica, supported by hundreds of others on several continents, had spent ten million dollars and massive amounts of professional time in an unprecedented attempt to solve a matter of critical importance to the health of planet Earth, and they had succeeded. They had an answer, even if some of the precise details of the equation were still in debate. But by November 1987, there was no significant doubt among competent scientists that without man-made chlorine in the Earth's atmosphere, there would be no springtime hole in the ozone over Antarctica. With the Montreal Protocol, the Antarctic findings, and the growing realization that the same process of ozone destruction was probably occurring over the Arctic as well, it would seem log-

ical that the CFC producers of the world—and *especially* the most responsible of all, giant Du Pont—would throw in the towel, dismantle their "tobacco institute"-style public relations body (known as Alliance for a Responsible CFC Policy), and admit that the products they were producing had now been tried and convicted of damaging our common atmosphere. Surely Du Pont would call for an immediate phaseout! After all, it was Du Pont that had hired a world-class, former NOAA scientist named Mack McFarland to keep them abreast of the latest scientific findings. McFarland, whose credentials and scientific honesty were beyond reproach, had even participated in the Punta Arenas expedition, and had already briefed Du Pont on the irrefutable evidence of CFC complicity that had been found in the stratosphere over Antarctica. Surely the giant chemical company couldn't justify waiting any longer, especially since CFC's were only a few percentage points of their overall business.

Yet when all the results were in and McFarland had briefed his employers that chlorine from CFC's was causing the hole in a strange process set up by meteorology, Du Pont's senior executives either never considered or flatly ignored the broader implications and pounced like a tiger on the unresolved issues between dynamics and chemistry, announcing that they would have to know *how much* of the ozone depletion was due to chlorine, and how much due to air mass movement, before a phaseout of CFC's would be "responsible" (a strange use of the word that sent several chemists to their dictionaries in puzzlement). It wasn't Mack McFarland's conclusion—it was the voice of profit-at-all-costs philosophy finally overriding good sense and responsibility. Du Pont had finally fallen from grace in the eyes of many scientists who had always felt more kindly toward their form of foot-dragging than toward the more radical defenders of CFC's who had wholly ignored the scientific realities from the start.

The events of fall and spring 1987–88 began to move with the speed of a musical comedy and the intricacies of a Kafka

story. The Natural Resources Defense Council, one of the most respected environmentalist groups, had filed a lawsuit against the EPA in 1984 to try and force them to implement Phase Two regulations (Phase One being the spray can ban announced in 1978). Finally, in the fall of 1987—with the lawsuit closing in on them—the EPA acted, but its action was a bitter disappointment to many who also felt that the CFC restrictions of the Montreal Protocol itself were far too tepid. Instead of using the latest hard-won information from Punta Arenas, which was open and available to everyone in government by then, the EPA simply blinded itself to the new realities and adopted the Montreal Protocol limitations as if the Punta Arenas Expedition had never occurred. It was as if the United States of America—whose scientists clearly knew otherwise now—was stating officially that the Montreal Protocol's limitation on CFC production (only a 50 percent cutback by the year 2000) was realistic and adequate. The fact that the EPA laced its announcement on December 1, 1987, with gratuitous references to the *costs* (in terms of corporate profits and jobs) of switching away from CFC's was not lost on the environmentalists of the nation. The EPA, after all, was still an animal of the Reagan administration, despite the leadership of Lee Thomas as an administrator who seemed to be scientifically engaged with the problems at hand. And there was still the fervent belief in administration circles that unilateral action by the United States would do nothing to propel the rest of the world toward more stringent CFC regulation and phaseout.

The inherent, inadvertent fraud of Montreal was the idea that a 50 percent cutback (which was actually a 35 percent cutback when the additional production allowances to the Third World are considered) would somehow stabilize ozone destruction. For the EPA to continue to rely on such clearly fraudulent expectations was, in the uncharitable view, a cynical sham, and in the *most* charitable view, a significant mistake in international diplomatic strategy.

To the CFC industry, however, the EPA action was a
lief.

In the periphery of the debate stood Bob Watson (the on
key scientist of the ozone issue who would not be able to
tend the Snowmass meeting he had orchestrated), Sher
Rowland, Mack McFarland, and numerous other top scie
tists who had come together at Watson's invitation to form t
Ozone Trends Panel after Don Heath had made his startli
announcement in 1986 that the TOMS satellite data fro
NIMBUS-7 were showing an overall worldwide drop in glob
ozone of 4 percent! If a worldwide 4 percent loss was a val
finding, it would be the first major evidence of global ozo
layer destruction.

There were, however, serious doubts over the accuracy o
that 4 percent figure.

NASA had been required by Congress to file its next two
year report on January 1, 1988, and Bob Watson (who ha
taken considerable pride in the fact that his agency had neve
been a day late with such reports) was faced with a dilemma
The Ozone Trends Panel results were to serve as the 198
NASA report, and they weren't ready. They hadn't had enoug
time to thoroughly analyze the mountain of new data that ha
been turned up. "We could write something," Watson told th
others, "but I don't think we'd be happy with it, or proud of it."
With reluctance, he made the decision to slip the date thre
months instead, scheduling the report for a March release.

The Trends Panel had convened to analyze the TOMS dat
and determine its accuracy, because there was firm knowl
edge that the TOMS spectrographic instrument itself had de
graded since launch, and was putting out erroneously lo
readings which were not being properly adjusted.[2] Since n
one could climb into orbit and physically inspect the satellit
(especially after the Challenger disaster of 1986), there wa
no way to find out directly. They would have to corroborat
the data with readings from somewhere else, and there wa
really only one other control source: the worldwide constella

tion of Dobson observation posts known loosely as the Dobson network, which could give them a baseline to analyze (though it was too poorly coordinated to function as a true network).

But the findings from that network covering the last decade had already been carefully analyzed by professional statisticians, and there was no clear, downward trend in total worldwide ozone. Unless somehow they were misinterpreting the Dobson network, the satellite data seemed to be a direct and unresolvable contradiction.

The TOMS data couldn't be broken down any further, so the Trends Panel decided to take the Dobson network readings apart, using a method Sherry Rowland had already pioneered when he and graduate student Neil Harris had investigated the 1983 ozone readings decline at Arosa, Switzerland. Rowland and Harris had taken the Arosa Dobson station's data and compared *different months* as separate data blocks rather than homogenizing the readings year round. When they also looked at other northern latitude stations, the two chemists had been surprised to find previously unidentified wintertime ozone losses in the 1983 data (losses that Rowland began to suspect might be caused by the extra stratospheric debris inserted by the El Chichón volcano in Mexico acting as reactive surfaces for *heterogeneous* reactions).[3]

Maybe, thought the Panel, there are variations in the data that disappear when the months and the various latitude bands are all lumped together and averaged. That would turn out to be an understatement.

As the work of breaking the Dobson network data apart progressed, all the members—including Mack McFarland—were sworn to secrecy, and even Bob Watson refrained from telling his superiors and colleagues at NASA what they were finding—even when the findings began to get frightening. All of them would wait until the final executive summary was written and released. Watson couldn't inform NASA, McFarland was prohibited from discussing the trends with Du Pont, and Rowland couldn't publish. The limitations were neces-

sary, but were a bit frustrating for some of the members, especially as December 1987 brought the reality that the chemical industry was going to keep dragging its heels over further CFC controls or phaseouts. With the industry thumbing its collective noses at the Antarctic results, the Trends Panel members by late January found themselves sitting uncomfortably on some very startling findings. There had been no consensus when Sherry Rowland presented his group's tentative conclusions to a meeting at the Trends Panel in Switzerland in December, but by late January and early February, the bombshell nature of the results was becoming an accepted reality. The Trends Panel in effect found themselves sitting on the very findings that would blow away the chemical industry's last line of defense.[4] It was tough to keep quiet until the formal release date, but they had no choice. Just as in the Airborne Expedition, the Trends Panel knew they had to have this one exactly right, thoroughly supported, and beyond scientific question by the time their findings hit the street—and the airwaves.

And in terms of global importance, their findings would be a quantum leap above those of Punta Arenas.

March 15 was rescheduled as the release date for the Trends Panel report, and Bob Watson found himself watching the clock, knowing instinctively that the debate that continued to rage through the winter season would be brought to a halt if only they could reveal what they already knew.

As Bob Watson wrestled with the decision to delay the Ozone Trends report in December 1987, an exhausted Susan Solomon was fielding a cheery call from John Meriwether, a physicist at the University of Michigan, whose field research had been based in far north Greenland, at the U.S.–owned Thule Air Force Base.

"Hey, wouldn't you like to come up here to balmy Greenland and see what's going on in the Arctic?"

Having planned a trip to Greenland as early as the previ-

ous June (before departing for McMurdo), Susan was instantly interested. Exhausted or not—instruments still unpacked and unchecked from McMurdo or not—Susan and her colleagues (George Mount, Ryan Sanders, and Roger Jakoubek) couldn't resist. By late January the atmospheric chemist who hated cold weather found herself once again wrapped up like a polar bear in an Arctic parka, this time near the top of the planet. The Arctic vortex—a weaker cousin of its Antarctic counterpart—had rolled over Thule the day they arrived, and by nightfall they were taking OClO measurements of the total column above the Greenland station.

There was one fifth as much OClO as over McMurdo, but that was still ten times more than normal. The temperatures at the appropriate altitude (30 millibars) overhead was in the $-80°$ to $-85°$ F range, which was just cold enough to emulate the Antarctic-style reactions in the polar stratospheric clouds, which were also overhead at Thule. Susan and her small team returned to Boulder in February, convinced that Bob Watson's intention to organize a Punta Arenas–style expedition to the Arctic in January 1989 was vital: "There is," she said, "evidence for anomalous chemistry taking place in the Arctic as well."[5]

But the embattled chemical manufacturers weren't in the mood to listen. As Susan's Aeronomy Lab team finally returned home to Boulder to stay and began unpacking their instruments at long last, a round of letters between Capitol Hill and Du Pont began that would demonstrate the depth of the major CFC producer's stubbornness—and leave a handful of senators virtually stunned.

Senator Robert Stafford of the Senate Committee on the Environment and Public Works had listened to testimony in an October 1987 hearing on ratification of the Montreal Protocol that deeply worried him. During the hearing, Sherry Rowland had once again trekked to the Hill to recommend immediate action to eliminate CFC's—action far beyond that of the Montreal Accord—while Mike McElroy of Harvard had

called the exclusion of Antarctic Ozone Hole awareness from Montreal "a mistake," and the National Science Foundation's Peter Wilkniss had described the Antarctic ozone hole as so worrisome and dangerous that he was now afraid for the safety of scientists traveling there to study it! It was all too obvious to Stafford that the chemical industry had no defenses left and must throw in the towel. As with the many scientists who had reached the same conclusion, the senator just naturally assumed that a company such as Du Pont merely needed a slight nudge. The evidence was already overwhelming, yet Du Pont and the rest of the CFC industry had been stonewalling any change in their posture since late fall, despite what seemed to Stafford and others to be the inevitable end of CFC's. And for every day of inaction by Du Pont and the other CFC producers worldwide, thousands more tons of CFC's—laden with chlorine atoms bound irrevocably for the stratosphere and eventual ozone destruction—were being produced and shipped.

Robert Stafford rounded up fellow Senate subcommittee members Max Baucus and Dave Durenberger—all of whom had finally reached the breaking point—and suggested what form the "nudge" should take. As a result, on February 22, 1988, the three senators signed a letter to Richard E. Heckert, the chairman of the board of Du Pont, which reminded him of the 1975 pledge of then–Du Pont chairman, Irving Shapiro: "Should reputable evidence show that some fluorocarbons cause a health hazard through depletion of the ozone layer, we are prepared to stop production of the offending compounds."

"It is time," the senators said bluntly, "to fulfill that pledge." Du Pont should cease production of CFC's immediately.

On March 4 they received an incendiary reply from Du Pont over Heckert's signature:

> Du Pont stands by its 1975 commitment to stop production of fully halogenated chlorofluorocar-

> bons if their use poses a threat to health . . . [but] . . . At the moment scientific evidence does not point to the need for dramatic CFC reductions. There is no available measure of the contribution of CFC's to any observed ozone change. In fact, recent observations show a decrease in the amount of ultraviolet radiation from the sun reaching the United States.

The words were infuriating, perplexing, and in the words of one staff member, "inherently dishonest." The so-called study referred to came from a February 12, 1988, paper in *Science* by the National Cancer Institute, who had simply reviewed the readings from a nonstandard, non-Dobson collection of UV-B meters arrayed around eight American cities and concluded that ultraviolet light had decreased between 1974 and 1985, without considering the effects of increasing smog and the UV-blocking potential of all forms of increased urban pollution.[6] The authors of the UV-B report had taken pains to deny in advance that their results lessened the ozone threat from CFC's, yet their work was promptly misused to prove exactly that. Despite the fact that the paper was effectively useless in the serious debate over CFC's and ozone loss potential, and despite the reality that it had been dismissed by the majority of the serious atmospheric scientific community, the Du Pont corporation (which fancied itself a bastion of responsibility) proceeded to gleefully use the report to counter the avalanche of evidence of the past twelve months!

"Incredible!" roared one environmentalist in particular, who, by his own admission, was becoming increasingly cynical by the day. "What the hell does it *take*? Apparently they're determined to keep selling CFC's until they have irrefutable evidence that CFC's have, in fact, killed all forms of life on the planet. Then and only then will they stop production. Anything short of that would obviously be considered inconclusive. Incredible!"

Du Pont had set itself up for an embarrassing fall. Within the month their chairman's letter would be hung around their collective necks like the deceased albatross of the ancient mariner, badly tainting later public relations attempts by Du Pont to paint an image of itself as having struggled mightily to stay up with the latest science and act immediately in the public interest. In the meantime, scientists such as Du Pont's own Mack McFarland—who knew the score—could only cringe in silence.

On March 14, 1988, the U.S. Senate ratified the Montreal Protocol by a steamroller vote of 83 to 0. The Protocol might not go far enough, but even to knowledgeable senators such as Stafford, Baucus, Durenberger, Gore, and Bumpers, who were determined that the United States do far more, it was an international start, and it was an agreement that had a built-in process for strengthening its provisions as the science became more overwhelmingly certain. Voting against doing *something*, in the distant hope that a tougher international pact could someday be concluded, was unrealistic and unthinkable, and even the environmentally knowledgeable senators supported the bird-in-the-hand pact, which at least acknowledged that "Chicken Little may have a point."

The name of Chicken Little had been invoked so many times by chemical industry representatives scornful of warnings about possible dire effects of CFC's on the Earth's life-supporting atmosphere that even journalists were beginning to forget the fictional little character came from a children's proverb, and not some university research lab. "There they go again!" had been the standard eye-rolling response to any new refinement of the CFC–ozone destruction theory and its consequences, especially if enunciated by Sherry Rowland.

On March 15, 1988, however, Chicken Little's sky did indeed fall—on those in the chemical industry who still held out any substantive hope that CFC–caused ozone destruction could be kept to acceptable levels with continued production of

the chemicals. The crushing weight of the Ozone Trends Report was too much.

The results had become so startling over the previous months that the Ozone Trends Panel members had suddenly become alarmed after a November meeting and redoubled their efforts to be absolutely sure they were seeing what they thought they were seeing in the data. "Before announcing something like *that*," said Watson, "we had to make sure we were absolutely right."

They were, and now it was time to tell the world.

In a nutshell, Don Heath's TOMS data had told only part of the story. It was well understood that the satellite-based spectrometers aboard Nimbus-7 had degraded over the past decade, but they still gave a sufficiently stable baseline of readings about atmospheric ozone from which the Panel could judge the ground-based Dobson network readings, culling out the bad and the unreliable readings that didn't show up in the satellite readings. By the same token, once the faulty Dobson stations were taken out of the loop, the good ground-based Dobson readings were used to calibrate the satellite readings. In effect, the systems bootstrapped each other, and in the end the Panel found that Don Heath's conclusions about how much global ozone had been lost were conservative: The overall loss in the Earth's ozone layer wasn't 4 percent as the TOMS data had shown; it ranged as high as 6 percent!

Bob Watson's consummate skill at political balance showed once again in the timing of every aspect of the release of what constituted the executive summary of the report. On the evening of the day the Senate had unanimously ratified the Montreal Accord, Watson began the process of alerting the Reagan White House of what was coming. There was no way in the face of an 83 to 0 vote that the Reaganites could block the Trends Report or dull its effect even if they tried, but with Watson's timing, there would be no opportunity to do so either.

Yet it would be improper (and politically dangerous) to blindside the administration, so the next morning—only two

hours before their press conference—Watson personally briefed several senior EPA people along with the president's science adviser, Bill Graham (who rightly or wrongly had acquired a reputation for a "go slow" philosophy toward CFC controls).[7] That took care of both the official scientific representative and the scientific policy-making sectors of government. At the same time—with one hour to go before the briefing—Mack McFarland briefed Du Pont and the Chemical Manufacturers Association on what was about to hit the fan. Not surprisingly, the top leadership of the company missed the significance of it all, if they even considered it to begin with.

The Trends Panel had used the Rowland-Harris method of breaking down the Dobson data, but had done so on a far larger scale. They had reexamined the Dobson network and broken down the trends in terms of seasons and latitude bands. When the Dobson network data had been averaged—because of the method used in averaging—there was no loss. When it was pulled apart, massive ozone losses jumped off the page for various latitudes at various times of the year and especially for the winter. The losses in the northern hemisphere were twice as large as the models had predicted and even larger than Sherry Rowland had originally warned. In fact, the level of global ozone loss was even greater than what was supposed to occur under the Montreal Protocol limitations *by the year 2075*—and this was 1988! In the latitude bands that cover the United States, Canada, Europe, China, Japan, and the U.S.S.R., very significant and worrisome losses had occurred each winter season from 2.3 to 6.2 percent and annually from 1.7 to 3 percent. The figures were far too great to be confused with statistical "noise." These were genuine. The residents of the northern hemisphere—billions of humans—were already receiving increasing doses of UV-B radiation due to one single factor: the insertion into the stratosphere of chlorine, borne by man-made chlorofluorocarbon molecules.

Further, the wintertime loss could indicate that cold weather heterogeneous reactions similar to those in Antarctica (but on a smaller reactive scale) could be occurring over mid-latitudes![9]

In addition, the Trends Panel pointed out that the approaching peak of the solar cycle (1991) would tend to increase the atmospheric production of ozone and mask the effects of chlorine destruction of ozone, but after 1991 the effects would begin to become even more apparent, the Antarctic and Arctic ozone holes would grow deeper and more pervasive, and the worldwide ozone losses could be expected to accelerate. If the CFC growth rate continued, the report added, the Earth's population could expect 10 percent of the ozone layer to be gone by 2060.

The effect on Du Pont was much more rapid and decisive than anyone had expected. After fourteen years of unyielding resistance to a challenge that could affect at best 2 percent of their business, Du Pont suddenly did an about-face, leaving the members of their CFC division stunned.

Mack McFarland had begun the process of getting Du Pont's leadership to understand the full significance of the findings after the press conference on March 15. At first, the senior leaders of the corporation had not understood. On March 18, however, McFarland got the chance to brief Chairman Heckert and the corporation's executive committee in person. The meeting ended with a simple decision: Du Pont's production of CFC's would end *as soon as* substitutes became available. With that decision, the corporation's considerable public relations machine began putting a positive-image spin on the upcoming announcement. Du Pont would embrace the decision as if it sprang from the heart of an overly concerned and conservative guardian of the environment.[10]

The fact that it had taken so many years of foot-dragging to get to that point would remain a matter of external debate, but in the end the decision would become a windfall of new profits for Du Pont. Although the company had long been

responsible for supplying 25 percent of the planet's CFC's, and 25 percent of the chlorine atoms involved in ozone destruction, now it could introduce new "environmentally safe" CFC substitutes at considerably higher profit levels than could ever be achieved with standard CFC's. Du Pont's leaders could see that the race to replace CFC's would eventually become frantic, as international regulations chased such products from the marketplace. The stampede of industry to switch to substitutes such as HCFC's (which had already entered the testing stage) would make the new replacement gases supply-sensitive, not price-sensitive. Du Pont, in other words, would be ready, willing, and able to cash in. The Earth's ozone layer and its human population might be losers in the long ozone war, but the Du Pont corporation would not be counted among those casualties.[11]

By the time the Snowmass conference finally convened less than two months later, the remainder of the CFC industry was rushing to examine Du Pont's action, the Trends Report findings, McFarland's interpretation, and the results of the Antarctic Airborne Expedition itself in order to decide whether to follow suit. To say the CFC industry was in some disarray would probably be an understatement.

For that matter, though, the Snowmass conference was somewhat in disarray as well.

Sixty-nine presentations—most of them backed by papers that would be refined and published in a final compilation many months later—were scheduled for a five-day period, and each group representing each paper had selected one of its number to take the microphone and explain their findings and conclusions. Those presentations were supposed to be strictly limited to a given time period (usually twenty minutes), but with the passionate interest and attention levels high (and with certain scientists spring-loaded to argue, question, and discuss everything from overall conclusions to niggling details), the various "presiding" scientists (the designated moderator was different for each half day) quickly lost control of

the schedule.[12] While the dynamicists staged no revolts and never varied from gentlemanly discussion, neither were they about to give up, and scientists such as Ka Kit Tung of Clarkson University (who had been responsible for the major thrust of the dynamical theory), Jerry Mahlman, Mark Schoeberl of NASA, Cambridge's Mike McIntyre, NASA's Richard Stolarski, and others worked hard to make certain the chemically based explanations presented on the third day weren't allowed to run away with the conclusions. For that matter, when the dynamicists had their turn on Thursday (day four), the chemists returned the favor, Susan Solomon (for one) neatly and skillfully disassembling one dynamicist in particular who had made the mistake of letting his evidentiary guard down while trying to reelevate the dynamics of the Antarctic ozone hole to unrealistic heights of importance.

Of course, behind the scenes was where the important exchanges took place—hallway conversations; evening get-togethers in many of the ski lodge, condominium-style rooms occupied by the scientists; discussions held while jogging, having dinner, playing golf, or simply leaning against a pickup truck in the parking lot during the lunch break. The formal presentations and papers and posters during such a conference form the basic stock for refining a major scientific issue, but the person-to-person exchanges provide the fermentation from which ultimate consensus—and new realizations—emerge.

On the fifth day, with everyone's ears full of words and heads swimming with ideas, there had in fact been general movement of the group in several directions. It was obvious, for instance, that while dynamics played a key role in Antarctica and could not be dismissed or minimized, chlorine chemistry was the key. Tuck's cornfield meet had indeed occurred.[13] There had been little consensus, but from the clashes had emerged a consistent understanding.

Moreover, there was no question that the urgency of the CFC situation was acute, whether or not the Antarctic hole

could spread to lower, more populated latitudes. The fact that anything had gone nonlinear in the formerly balanced equation of atmospheric ozone creation and destruction was now established fact, as was the role of heterogeneous atmospheric reactions (thanks to the pivotal laboratory work in 1987 by Mario Molina). And from all that came many new understandings, including the fact that the Arctic Airborne Stratospheric Expedition scheduled for 1989 was indeed vital. If there was a hole in the ozone layer each winter over the northern ice cap, however weak it might be, it could already be affecting millions of people.

For Susan Solomon there were few real surprises at Snowmass. Being on the leading edge of her subject meant her role was one of refinement and support for the various theoretical explanations that were now jelling nicely.

There was, however, one rather profound shock—the hint of a dark possibility—that arose in her mind from the words and the presentation of a scientist from Menlo Park, California.

Dr. Margaret A. "Maggie" Tolbert, a bright young scientist from SRI International in Menlo Park, California, had presented a paper on the second day of the conference about heterogeneous chemistry in the stratosphere related to Antarctic Ozone depletion. Her early work had concerned the tiny chemical reactions on the face of the ice crystals in the PSC's. Her new studies showed that there was no guarantee the very same reactions at the very same speeds couldn't occur on other tiny surfaces.[14]

Certainly there was no real possibility of Polar Stratospheric Clouds over mid-latitudes of the Earth. Susan's January trip to Thule, Greenland, had given her reason to believe that PSC's were generally rather minimal even over the north polar regions. So to the ear of the casual observer at Snowmass, Tolbert's work on heterogeneous reactions could not really concern the bulk of the Earth's human population.

Or could it?

Susan Solomon had already read extensively about the various mixture of particles that could from time to time be injected into the stratosphere. Most of them were in volumes too small to worry about, but there had been much speculation that the same type of reactions that took off at a high rate of speed on the surface of the PSC ice crystals might find a similar reaction crucible on the surface of volcanic debris.

The Mexican volcano of El Chichón in 1983 had injected large amounts of tiny particles in the stratosphere that might have caused (through heterogeneous reactions) a small ozone drop.[15] El Chichón was a big eruption, but there had been other historical eruptions far larger, such as the explosion of Krakatoa in the nineteenth century. That's where a cold feeling of genuine worry began to crawl around the back of Susan's mind, expressed in a single question she began asking herself: "What if we have another Krakatoa?"

"I wasn't scared," Solomon would explain later, "until I saw Tolbert's paper. People like Tolbert who have done these surface reactions are now starting to do them on sulfuric acid aerosols at warmer temperatures, which is what you have, for instance, over Boulder. And you know what? They're finding that the reactions go [at greatly accelerated rates], and that's really frightening." The sulfuric aerosols Tolbert had considered took the place of PSC's in providing a reaction surface, though exactly what the potential was would have to wait for more research.[16] Susan had begun thinking by the end of Snowmass of what she could do to push the research further, including, perhaps, collaborating on a paper, perhaps with Dave Hofmann, who had studied these perhaps for more than a decade. If there was any possibility that such nonlinear reactions could really occur in moderate temperatures over mid-latitudes, the sooner the information was confirmed and given to the policymakers the better.

"I mean," she said, "if it's only going to be a polar phenomenon, clearly that's good in a lot of ways . . . but what if you *do* have Krakatoa? We've loaded the stratosphere with chlorine,

with more arriving every hour and for the next fifty years at least. The world could literally be a time bomb. The bottom line is that we've been putting chlorine into the atmosphere on a time scale that is minuscule compared with the geologic time scales. With the current loading of chlorine in the atmosphere, and if these people are right about those surface reactions taking place on those aerosols, you could see some changes here that have the potential for biological catastrophe. I'm not saying that if something like [Krakatoa] were to take place it would wipe out life on Earth as we know it, but it would have serious crop damage effects and could easily cause other kinds of agricultural disasters. Obviously right now [these theories] are very uncertain and we need to understand the chemistry of these aerosols a lot better than we do, but it's frightening. And *I'm* frightened."

The last word at Snowmass, figuratively and literally, went to the battered master who had quietly and calmly stayed his course for fourteen years, Sherry Rowland. Snowmass had in some respects provided the final validation of the concerns raised by Sherry Rowland and Mario Molina's work, expanding exponentially the original finding that CFC–borne chlorine can destroy ozone.[17] In terms of the scope and breadth of the atmospheric chlorine chemistry presented by scores of scientists within the five-day conference, the meeting was pivotal—but it was still Mario Molina (who spoke at the start of the last session on his latest chlorine species research) and Sherry Rowland who had originally sounded the alarm. Of the two, Rowland had been the lightning rod.

With his half glasses and sonorous voice, Rowland's presence as always was soothing, his image that of the steady, unflappable professor. He rose to the dais as the last speaker of the Polar Ozone Workshop and threw down a new gauntlet before his fellow scientists (some of whom were former students). While the chlorine-ozone issue was now thoroughly exposed (if not yet resolved) there were other major challenges

on the stratospheric agenda that Sherry Rowland knew the atmospheric scientific community had to face, and the startling and somewhat inexplicable rise of methane levels was one of them. Methane, which comes from the guts of cows, termites, and rice paddies among other anaerobic (without oxygen) sources, is a greenhouse gas when it stays in the troposphere. Exactly why it's increasing no one really knows, nor is there a definitive explanation for what source is causing the worldwide measurable increase. But with more methane in the troposphere, global warming speeds up.

Sherry Rowland had identified another worry. Methane (CH_4) in the troposphere ends up transported upward through the tropical tropopause (near the Equator) into the stratosphere, and, once there, breaks down to form water (H_2O), which in turn can increase the worldwide concentration and duration of polar stratospheric clouds, which provide more of a reactive surface for ozone destruction.

Rowland (who had worked on the problem with one of his graduate student research associates, Donald Blake) delivered a short paper on the subject and sat down, saying not a word about the main focus of the conference. The fight was not over. CFC's were still being manufactured and the world was still spewing carbon dioxide skyward at a furious rate while methane and nitrous oxide concentrations increased daily. Snowmass marked a milepost, not a destination.

In other words, the battle for the health of the Earth's atmosphere has barely begun, and because of the economic and political forces that will resist change in the absence of actual evidence of damage, without a vibrant and engaged atmospheric scientific community energetically looking for the evidence and the answers, the ozone debacle will be repeated. Nothing will be done until major, possibly catastrophic, damage has already become inevitable.

Within a month, another quiet and studious scientist of world-class reputation would sit before a sympathetic Senate subcommittee and offer a reasoned opinion that would put his

career, his reputation, and his credibility under worldwi attack, all for expressing a singular thesis: The effects of gl bal warming are already with us.

As the Snowmass delegates departed—and the temper tures around the United States climbed alarmingly—th stage was once again set by nature for a play with all the sam plot features of the ozone trilogy. There would be theories an scathing, sneering rejection of the theories and the theorist there would be environmental groups pitted against industri alists and politicians; there would be an old president and new president both moved to dynamic inaction in the face o conflicting scientific evidence. Once again there would be press, a public, and a political establishment unable to under stand what science was trying to communicate.

But this time, the global and national stakes would be even greater.[18]